IN THE U.S. PATENT AND TRADEMARK OFFICE

Appl. No.	:	10/718,837
Applicant	:	Raghothaman, et al.
Filed	:	November 21, 2003
TC/AU	:	2616
Examiner	:	Pasia, Redentor M.
Docket No.	:	873.0134.U1(US)
Customer No.	:	29683
Title	:	FLEXIBLE RATE SPLIT METHOD FOR MIMO TRANSMISSION

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

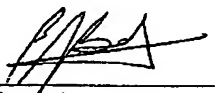
DECLARATION UNDER 37 C.F.R. § 1.131

1. I, Balaji Raghothaman, hereby attest that I am a joint and first inventor with Jianzhong (Charlie) Zhang of the invention described and claimed in the above-referenced patent application now pending before the U.S. Patent Office.

2. We conceived of the invention at least as early as June 16, 2003, as indicated by Exhibit A attached hereto in eight dated pages entitled "Flexible Rate Split Method for MIMO Transmission". Each of those eight numbered pages bears both our names and that date along the top margin. Exhibit A represents our own work.

3. I hereby attest that Exhibit A is a true copy of our original paper, and that we conceived of the invention described in Exhibit A within the United States. I hereby acknowledge that the statements made herein are true or are made on information and belief that is believed to be true. I further acknowledge that any willful false statements are punishable by fine or imprisonment, or both, in accordance with 18 U.S.C. § 1001; and that such false statements may jeopardize the validity of any patent that may issue from the application to which this Declaration pertains.

Respectfully Submitted,



Balaji Raghothaman

2 Nov. 2007
Date

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Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

DECLARATION UNDER 37 C.F.R. § 1.131

1. I, Jianzhong (Charlie) Zhang, hereby attest that I am a joint and first inventor with Balaji Raghothaman of the invention described and claimed in the above-referenced patent application now pending before the U.S. Patent Office.

2. We conceived of the invention at least as early as June 16, 2003, as indicated by Exhibit A attached hereto in eight dated pages entitled "Flexible Rate Split Method for MIMO Transmission". Each of those eight numbered pages bears both our names and that date along the top margin. Exhibit A represents our own work.

3. I hereby attest that Exhibit A is a true copy of our original paper, and that we conceived of the invention described in Exhibit A within the United States. I hereby acknowledge that the statements made herein are true or are made on information and belief that is believed to be true. I further acknowledge that any willful false statements are punishable by fine or imprisonment, or both, in accordance with 18 U.S.C. § 1001; and that such false statements may jeopardize the validity of any patent that may issue from the application to which this Declaration pertains.

Respectfully Submitted,

Jianzhong (Charlie) Zhang

11/14/07
Date

Nokia Research Center
Balaji Raghothaman, Jianzhong Zhang

06-16-2003

Flexible Rate Split Method for MIMO Transmission

Balaji Raghothaman, Jianzhong Zhang,
NRC Dallas.

Nokia Research Center
Balaji Raghothaman, Jianzhong Zhang

06-16-2003

1 Introduction

Practical schemes utilizing multiple antennas in wireless communications were initially geared towards achieving diversity gain [3], [4]. Space-time coding work was concentrated mainly on achieving the best possible performance with only the channel distribution known at the transmitter. Parallely, the assumption that the instantaneous channel information is available at the transmitter produced work in transmission beamforming [8], [9], antenna selection [10] etc. The methods mentioned above dealt with transmissions that have a channel rate of 1 symbol per channel use or lower. All these diversity methods can be used even when there is only one receiver antenna. When multiple receiver antennas are available, these antennas were simply used to add receiver diversity gain.

The achievable capacity of MIMO wireless communications in the presence of multiple transmitter *and* receiver antennas was perceived to be much larger, as described in the work by Telatar [1], and by Fochsini and Gans [2]. A step towards achieving that capacity was taken by the introduction of the layered space-time achitecture [5], also known as *diagonal BLAST*, which explains how the multi-dimensional channel can be used to deliver several one-dimensional streams of data, in an environment where the Rayleigh fading channel is *known at the receiver, but not at the transmitter. V-BLAST*, which is a simpler implementation, advocates a simple demultiplexing of the data stream instead of some specific encoding in space-time [17]. The corresponding receiver architecture for V-BLAST is also simpler [12]. A step closer towards achieving capacity is taken by assuming the availability of some channel information at the transmitter. The *PARC* method[11] is an example of such a technique. Here, the two antennas are allotted variable rates according to their respective channel conditions. The encoding is done separately on these two streams. In such a situation, the optimal receiver (in a capacity-achieving sense) was discussed by Varanasi and Guess in [6],[7]. The other aspect, which has to be used in conjunction with rate control of the different streams, is the transmission the streams over eigen-beams rather than over separate antennas. This was originally indicated by Telatar in [1], and elaborated upon by several others, eg. [14], [15]. It has to be noted, however, that the availability of channel information cannot be taken for granted, since it involves some reciprocity assumptions in the channel, or some feedback from the receiver. When partial channel knowledge is available, a criterion for switching between diversity and multiplexing was discussed in [16]. Recently, multiplexing mechanisms specific to CDMA, which combine code multiplexing with space-time multiplexing, are presented in [13].

2 Flexible Rate Split MIMO

Flexible Rate MIMO is a closed loop MIMO concept. It is a possible alternative to Lucent's PARC [11], [18] . Simulation results have shown that it outperforms PARC. It is also a tractable extension of the current PDCH structure. The Flexible Rate Split MIMO concept provides a method to transmit in the currently defined data rates in 1X-EV-DV more efficiently. At the same time, the peak rates can be increased by additional entries to the link adaptation table. The current configuration of the packet data channel in the 1X-EV-DV forward link is shown in Figure 1. The PARC proposal suggests the transmission of two separate packets, each with a different packet size and modulation/coding scheme. This method is illustrated inFigure 1. Two information packets of sizes N_1 and N_2 are encoded separately and transmitted. In contrast, the FRS approach shown inFigure 3, encodes all the N bits, where $N = N_1 + N_2$, into a single packet, and then distributes it into two streams. If the distribution consists of blind demultiplexing, then we arrive at the VBLAST algorithm. FRS-MIMO advocates an intelligent method of distributing the encoded packet into two substreams for MIMO transmission. The systematic bits are divided into two sets of different sizes N_1, N_2, and similarly the parity bits are divided in the same ratio. Then sub-packet selection algorithm acts independently on each of these two streams to obtain the required rate of transmission. For the first packet transmission, this selection

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Balaji Raghothaman, Jianzhong Zhang 06-16-2003

procedure consists simply of transmitting all the systematic bits and then as many parity bits as necessary. This procedure creates two streams with different rates attached to them, similar to the PARC procedure. The difference is that, in FRS-MIMO, the information bits are two encoded and interleaved across space and time, whereas in PARC, they are encoded only across time. Also, FRS-MIMO uses an interleaver of size N in its single turbo encoder, as opposed to PARC, which uses two turbo interleavers of smaller sizes N_1 and N_2 respectively in its two turbo encoders. Since the size of the interleaver of a turbo encoder has a bearing on its performance, there is an additional gain associated with FRS-MIMO over PARC.

Once the two individual streams have been created, they are transmitted across multiple antennas. The transmission can take the following several forms:

- The two streams can be transmitted across two antennas, with a power imbalance. The stream carrying more information bits (hence higher rate) is assigned more power, while the stream carrying lesser information is assigned lesser power, while confirming to an overall total power constraint.
- The two streams can be transmitted over two eigenmodes across multiple antennas. This entails the transmission of both streams over all the antennas, with suitable weighting. Here the number of transmitter antennas can be greater than two.

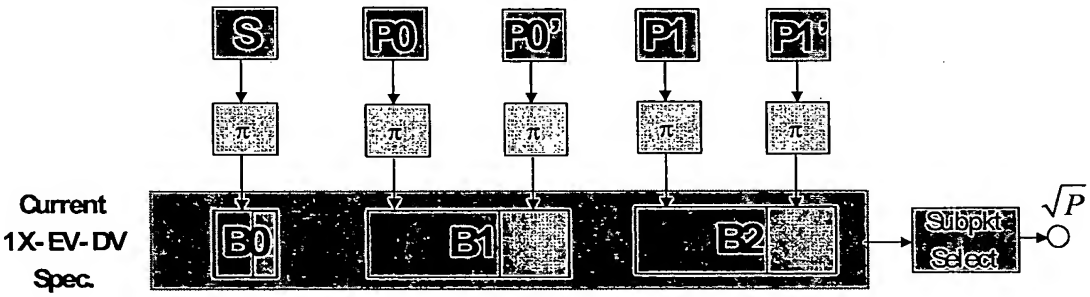

Figure 1. Packet Data Channel in 1X-EV-DV

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06-16-2003

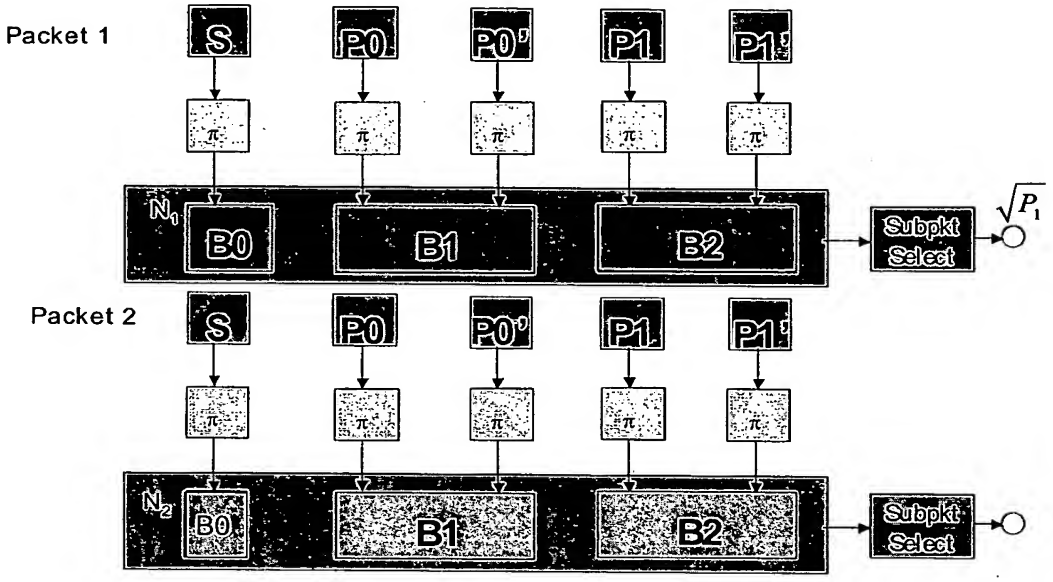

Figure 2. Per antenna rate control

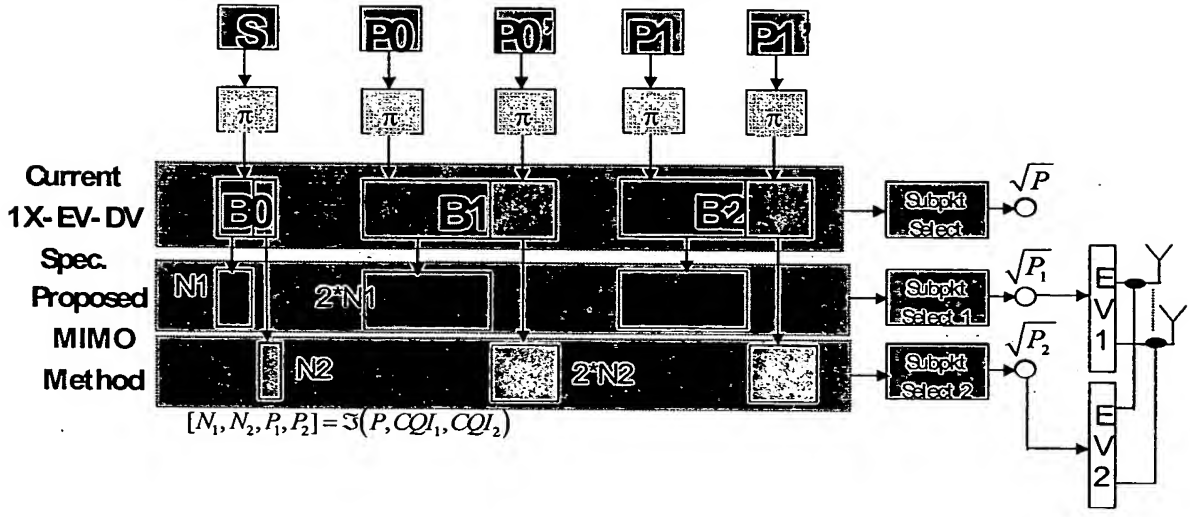

Figure 3. Flexible Rate Split MIMO

Several strategies can be used to divide the power and rate among the two streams. One such technique based on the resultant capacity of the transmission is given in [11]. Let two streams be transmitted with powers P_1 and P_2 respectively from two antennas. Let the MIMO transmission be received by two receiver antennas. Let the flat channel vector (a matrix form frequency selective fading channels) emanating from the first antenna be given by $\mathbf{h}_1$ and from the second antenna by $\mathbf{h}_2$. Let there be an additive Gaussian noise of variance σ^2. Then, the capacities of the first and second streams are given [11] by

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$$C_1 = \log\left(1 + P_1\mathbf{h}_1^H\left(P_2\mathbf{h}_2\mathbf{h}_2^H + \sigma^2\mathbf{I}\right)^{-1}\mathbf{h}_1\right),$$
$$C_2 = \log\left(1 + P_2\mathbf{h}_2^H\left(P_1\mathbf{h}_1\mathbf{h}_1^H + \sigma^2\mathbf{I}\right)^{-1}\mathbf{h}_2\right)$$

Using Lagrangian maximization with a total power constraint, the powers P_1 and P_2 can be determined, and hence the rates associated with them. This approach assumes that the first stream is detected correctly and cancelled from the second stream. This assumption is not always true. However, this method provides a straightforward way of performing the power split, and it has been adopted in the simulations below. Other methods of allocating power and rate include, for example, based on minimizing the average expected probability of error given the channel conditions.

The advantage gained by the FRS-MIMO method over the PARC method is mainly in two aspects:

- The packet is encoded and interleaved across space, in addition to time. This ensures that different portions of the packet encounter different channels, even when there is quasistatic fading. Telatar[1] states that encoding across space and time is better even in a bit-error-rate sense.
- The packet is encoded as one entity rather than two smaller packets. Hence the interleaver in the turbo-encoder is longer and provides more gain.
- There is scope for more advanced iterative decoder/receiver structures in the FRS-MIMO method, as compared to the PARC structure.

3 Simulations

In this section, link level simulation results are provided to demonstrate the FRS-MIMO technique. Packets of 1560 information bits were processed using the current 1X-EV-DV packet data channel framework for encoding. Flat quasistatic fading channels were generated for a 2Tx-2Rx antenna configuration. Note that, in a system level simulation, the packet size is not restricted to a single quantity, but can rather vary. The size of the packet will be a function of the total channel quality. The concept of FRS-MIMO is applicable in such a scenario also, even though these link level simulations use a fixed packet size.

Two receiver structures were used:

A. Max-SINR, no successive cancellation :

The receivers for the two streams are given by:

$$\mathbf{w}_1 = \left(P_2\mathbf{h}_2\mathbf{h}_2^H + \sigma^2\mathbf{I}\right)^{-1}\mathbf{h}_1$$
$$\mathbf{w}_2 = \left(P_1\mathbf{h}_1\mathbf{h}_1^H + \sigma^2\mathbf{I}\right)^{-1}\mathbf{h}_2,$$

where $\mathbf{h_1}$, $\mathbf{h_2}$ are the vectors depicting the channels emanating from antenna 1 and 2 respectively, P_1, P_2 are the powers of the two streams and σ^2 is the variance of the noise, modeled as AWGN.

B. Max-SINR for stronger stream + ideal cancellation of the first stream while detecting the second:

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Balaji Raghothaman, Jianzhong Zhang

In this method, the first stream is detected using the receiver $\mathbf{w}_1$ as above. The second stream is detected after canceling the interference from the first. In actuality, one has to use the detected symbols of the first stream in order to perform this cancellation. Thus any errors in detected the first stream is propogated to the cancellation process also. In our simulations, the cancellation is idealized, in that, for the purposes of the cancellation, the first stream is assumed to have been received perfectly.

The effective BLER is plotted against SNR is plotted in Figure 4. In V-BLAST and FRS-MIMO, the calculation of the BLER is straightforward, since there is only one encoded packet at each iteration. In PARC, the effective BLER is derived from the throughput, since there are two packets of varying sizes at each instant.

In both case A and case B, as shown in FRS-MIMO is seen to be better than V-BLAST and PARC.

The usage of eigenvectors in addition to rate and power splitting is not modeled in these simulations. This aspect can be expected to further improve the performance of FRS-MIMO over PARC.

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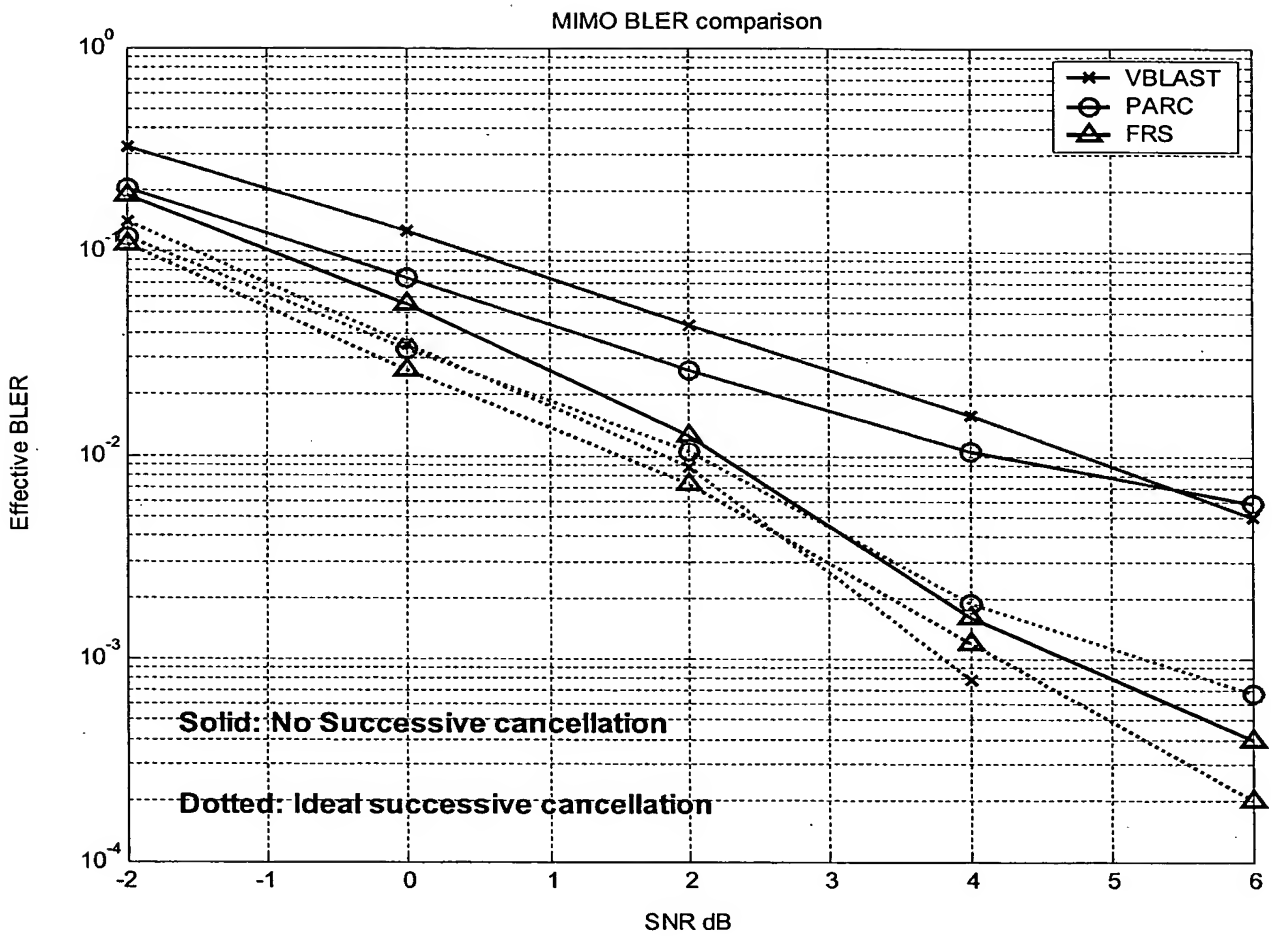

Figure 4. MIMO: V-BLAST vs. PARC vs. FRS comparison

4 References

[1] Telatar, Capacity of multi-antenna gaussian channels, Bell Systems Technical Journal, 1995.
[2] Fochsini and Gans, On the limits of wireless communications in a fading environment when using multiple antennas, Wireless Personal Communications, 1998.
[3] Naguib, Tarokh, Seshadri and Calderbank, A space-time coding modem for high-data-rate wireless communications, IEEE JSAC, Oct. 1998.
[4] Alamouti, A simple transmitter diversity technique for wireless communications, IEEE JSAC 1998.
[5] Fochsini, Layered space-time architecture for wireless communication in a fading environment when using multi-element antennas, Bell Systems Technical Journal, Fall 1996.
[6] Varanasi and Guess, Bandwidth-efficient multiple-access via signal design for decision feedback receivers: Towards an optimal spreading-code trade-off, Globecom 1997.
[7] Varanasi and Guess, Optimum decision feedback multiuser equalization with successive decoding achieves the total capacity of the Gaussian multiple-access channel, Asilomar 1998.
[8] Farrokhi, Liu and Tassiulas, Transmit beamforming and power control for cellular wireless systems, IEEE JSAC, Oct. 1998.
[9] Gelrach and Paulraj, Adaptive transmitting antenna methods for multipath environments, Globecom 1994.
[10] Winters, Switched diversity with feedback for DPSK mobile radio systems, IEEE Tran. Veh. Tech., Feb 1983.

[11] Chung, Lozano and Huang, Approaching eigenmode BLAST channel capacity using V_BLAST with rate and power feedback, VTC Fall 2001 .
[12] Fochsini, Reinaldo, Valenzuela and Wolniansky, Simplified processing for high spectral efficiency wireless communications employing multi-element arrays, IEEE JSAC, Nov 1999.
[13] Huang, Viswanathan and Fochsini, Multiple antennas in cellular CDMA systems: Transmission, detection and spectral efficiency, IEEE T-Wireless, July 2002.
[14] Ivrlac and Nossek, MIMO eigenbeamforming in correlated fading, ICCSC 2002.
[15] Sampath, Stoica and Paulraj, Generalized precoder and decoder design for MIMO channels using the weighted MMSE criterion, IEEE Tran. Comm. Dec. 2001.
[16] Heath and Paulraj, Switching between multiplexing and diversity based on constellation distance, Allerton 2000.
[17] Wolniansky, Fochsini, Golden and Valenzuela, V-BLAST: An architecture for realizing very high data rates over the rich-scattering wireless channels, Signals, Systems, and Electronics, 1998. ISSSE 98. 1998 URSI International Symposium, Sep 1998.
[18] Lucent, MIMO architecture proposal for F-PDCH, 3GPP2 TSG-C, C50-20011203-042, 2001.

Patent-Agency Harrington-Smith (EXT-RES/Usa)

From: Shaw Steven (Nokia-IPR/Dallas) Sent:Mon 8/18/2003 11:45 AM
To: Patent-Agency Harrington-Smith (EXT-RES/Usa)
Cc: Zhang Charlie (NRC/Dallas); Raghothaman Balaji (NRC/Dallas)
Subject: New application NC17678
Attachments: 17678.zip(527KB) 9634627.zip(3MB)

<<17678.zip>>
Please prepare a non-provisional patent application for the attached Invention Report. There are no hard dates by which to file the patent application. There will be a submission to a standard body toward the end of the year. Will will update you with an exact date and the material which will be submitted. The soft date is October 18, 2003.

Although an exhaustive search has not been preformed--the attached publications in zip file 9634627 should be in an IDS.

<<9634627.zip>>

Best Regards/Terveisin,

Steven Shaw
IPR Legal Counsel
Intellectual Property Rights
Nokia Inc.
Nokia Mobile Phones
6000 Connection Drive
Mail Drop 1:4-755
Irving, TX 75039
Office 1:453
Phone (972) 894-6173
Fax (972) 894-5619
Mobile (469) 231-7802

<<17678.zip>> <<9634627.zip>>

Exhibit B

From: Shaw Steven (Nokia-IPR/Dallas) Sent:Thu 9/25/2003 2:07 PM
To: Patent-Agency Harrington-Smith (EXT-RES/Usa)
Cc:
Subject: FW: 17678 Flexible Rate Split Algorithm for MIMO
Attachments:

Please bring 17678 to top of to do list. I would forward the paper to you when I have received it. Sorry for the change in priority dates.

BR,

Steven

> -----Original Message-----
> From: Raghothaman Balaji (NRC/Dallas)
> Sent: Thursday, September 25, 2003 10:57 AM
> To: Shaw Steven (Nokia-IPR/Dallas)
> Subject: RE: 17678 Flexible Rate Split Algorithm for MIMO
>
> Hi Steven,
>
> Yesterday I had sent an email saying that mid-October is ok.
> BUT, upon further discussion, we have changed our mind. We would like to file a provisional and submit the paper as soon as possible, since we think that there are some other groups around the country working on this problem, and we don't want to take chances. Please let me know if this is ok with you.
> As I said in my earlier email, I will give you a draft of the paper by Monday or tuesday.
>
> Regards,
> Balaji
>
> -----Original Message-----
> From: Shaw Steven (Nokia-IPR/Dallas)
> Sent: 23 September, 2003 11:49
> To: Raghothaman Balaji (NRC/Dallas)
> Subject: RE: 17678 Flexible Rate Split Algorithm for MIMO
>
> I gave them a soft date of October 18. They are starting drafting and can incorporate your latest proposed paper. Do you need the application filed earlier then mid October?
>
> BR,
>
> Steven
>
> << Message: RE: 17678 Your Ref: 873.0134.U1(US) >>
>
> -----Original Message-----
> From: Raghothaman Balaji (NRC/Dallas)
> Sent: Monday, September 22, 2003 1:49 PM
> To: Shaw Steven (Nokia-IPR/Dallas)
> Cc: Patent-Agency Novakov (EXT-RES/Dallas)
> Subject: RE: 17678 Flexible Rate Split Algorithm for MIMO
>
> I am massaging the paper draft. Will send you in a few days.
> If the patent application draft is in an advanced stage, then we can think of waiting for that instead of doing a provisional. Is

Exhibit C

there some indication of when the patent app draft will be ready ?
>
> Regards
> Balaji.
>
> -----Original Message-----
> From: Shaw Steven (Nokia-IPR/Dallas)
> Sent: 22 September, 2003 13:46
> To: Raghothaman Balaji (NRC/Dallas)
> Cc: Patent-Agency Novakov (EXT-RES/Dallas)
> Subject: RE: 17678 Flexible Rate Split Algorithm for MIMO
>
> Any disclosure outside Nokia may affect the novelty of non-US applications.
>
> We can file a provisional, based on what you plan to disclose and follow-up with the formal application. Do you have a draft of the paper yet?
>
> BR,
>
> Steven
>
> -----Original Message-----
> From: Raghothaman Balaji (NRC/Dallas)
> Sent: Monday, September 22, 2003 1:37 PM
> To: Shaw Steven (Nokia-IPR/Dallas)
> Subject: 17678 Flexible Rate Split Algorithm for MIMO
>
> Hi Steven,
> Is Bob Kelly doing the patent application for 17678 ?
> We would like to submit a paper to a journal based on this idea in the very near future. My understanding is that submission to a confidential peer review does not constitute disclosure... But please clarify. Should I wait for the patent application to be submitted ?
>
> Regards,
> Balaji

Patent-Agency Harrington-Smith (EXT-RES/Usa)

From: Patent-Agency Harrington-Smith (EXT-RES/Usa) **Sent:** Thu 10/9/2003 6:07 AM
To: Raghothaman Balaji (NRC/Dallas)
Cc:
Subject: Flexible Split Rate MIMO invention
Attachments:

Hello Mr. Ragothaman,
I am drafting a patent application for your split rate MIMO invention and would like to discuss it with you to clear up some points on which I am not clear. I left you a voice mail on Monday, but I fear you may not have received it. Please call me at 203/925-9400, ext 12, at your convenience when you have some time. Nokia has asked that we get this application filed right away, so I'd like to get a draft out for your review as soon as possible.
Best Regards,
Jerry Stanton

Exhibit D

Patent-Agency Harrington-Smith (EXT-RES/Usa)

From: Raghothaman Balaji (NRC/Dallas) Sent:Thu 10/23/2003 10:53 AM
To: Patent-Agency Harrington-Smith (EXT-RES/Usa)
Cc:
Subject: RE: Flexible Split-Rate MIMO: NC17678 (873.0134)
Attachments: 873.0134DftPatAppl'n-Balaji'sComments.doc(123KB)

Hi Jerry,
Please find comments in the attached document.
More comments will follow, focussing more on the claims. I will also try to give a concrete example as you had asked.
Sorry for the delay.. things have been pretty hectic.

Regards,
Balaji.

-----Original Message-----
From: Patent-Agency Harrington-Smith (EXT-RES/Usa)
Sent: 17 October, 2003 13:36
To: Raghothaman Balaji (NRC/Dallas)
Subject: RE: Drawings for Flexible Split-Rate MIMO: NC17678 (873.0134)

Hello Balaji:
Attached is a draft patent application for your FRS-MIMO invention with your new figure incorporated as Figure 4. I used it to replace the former FRS-MIMO packet diagram from your original disclosure, which overlaps the new drawing. This draft has not yet been reviewed by my supervising partner, Harry Smith, but I wanted to get this to you prior to the weekend since I think our time is running short. Two areas in the detailed description section in bold pose questions for you that I think we should answer in the text, even if they don't broaden the claims. The second, a detailed example with feedback and sizes of subpackets and transmission packets, will greatly help from an enablement perspective. Also, for Figure 4, should the turbo coder block 66 extend to include the blocks of bits 68, 82, the interleavers 70, and the combiners 84? How does Fig. 4 square with the preferred embodiment that uses a single interleaver of size N, where the input packet is size N?

Thanks for the new drawing, and I hope we can get this finalized prior to your presentation. Please provide any comments by phone (203/925-9400, ext 12), fax (203/944-0245), or email at your convenience, and also let me know when you will be making your presentation or submitting your paper so I know the deadline to have this filed.
BR,
Jerry Stanton

> -----Original Message-----
> From: Raghothaman Balaji (NRC/Dallas)
> Sent: Fri 10/17/2003 11:09 AM
> To: Patent-Agency Harrington-Smith (EXT-RES/Usa)
> Cc:
> Subject: RE: Drawings for Flexible Split-Rate MIMO
>
> Hi Jerry,
>
> I am attaching a figure which will hopefully give a clearer picture of the algorithm.
>
> Regards,
> Balaji.

Exhibit E

Patent-Agency Harrington-Smith (EXT-RES/Usa)

From: Raghothaman Balaji (NRC/Dallas) Sent:Mon 11/10/2003 2:04 PM
To: Patent-Agency Harrington-Smith (EXT-RES/Usa)
Cc:
Subject: RE: NC17678 Revised Draft, FRS-MIMO
Attachments: NC17678Draft10-24wChanges_11-08Balaji.doc(132KB)

Jerry,

Here is the document with my comments.

Regards,
Balaji.

-----Original Message-----
From: Patent-Agency Harrington-Smith (EXT-RES/Usa)
Sent: 03 November, 2003 09:43
To: Raghothaman Balaji (NRC/Dallas)
Subject: NC17678 Revised Draft, FRS-MIMO

Hello Balaji:
Attached is a revised draf per your comments of 10-23. I apologize for not sending this sooner, but I was expecting you to send me a more detailed example to put into the text before your next review. The figures are attached as a separate .pdf, and changes to the text are highlighted for your convenience.
BR,
Jerry

<<NC17678Draft10-24wChanges_11-08Balaji.doc>>

Exhibit F